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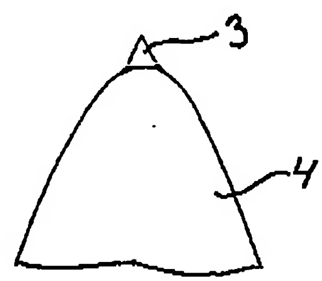
(54) Title: THE USE OF A TURBULATOR FOR DAMPING STALL VIBRATIONS IN THE BLADES OF A WIND TURBINE

(57) Abstract

A turbulator is arranged on the leading edge of a blade (4) for damping or completely preventing stall vibrations in wind turbine blades. The turbulator may be formed as a strip (3) with an equilateral, triangular cross section and arranged substantially in the stagnation point. The length of the strip may be in the range of 2.5 % of the length of the blade and may be mounted from a radius of 15 % from the blade tip and towards the centre.



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Title: The use of a turbulator for damping stall vibrations in the blades of a wind turbine.

Technical Field

The invention relates to the use of turbulator for damping or completely preventing stall vibrations in wind turbine blades and to a wind turbine having a blade provided with a turbulator. The expression "turbulator" denotes in this context a turbulence inducing means.

Background Art

It is known that so-called stall vibrations occur in the wind turbine blades under operation high winds. The vibrations may occur both in flap-wise direction (ie perpendicular to a plane through the leading and trailing edge of the blade) and in edge-wise direction (ie in the plane through the leading and trailing edge of the blade) as well as in combined directions. The stall vibrations can be very severe and seriously reduce the life of the blades. A particularly adverse circumstance is that the symmetrical condition in the edge-wise vibration state, in which two blades vibrate in phase opposition, often makes it difficult to recognise the stall vibrations from the stationary part of the wind turbine. The blades may thus be in a critical state with high vibration amplitudes without error signals being given by a normal vibration warning device.

It is known that stall vibrations mainly occur on certain blade types and maybe even only when using certain types of wind turbines. The reason herefor is not commonly known and no analytic methods exist to pre-determine whether a given blade type, possibly in connection with a specific type of wind turbine, will cause stall vibrations.

Tests carried out by the inventors have shown that a great risk of stall vibrations in a given blade type is involved when the blade is mounted on one type of wind turbine having certain structure dynamic properties and only a small risk or none at all is involved when the blade is mounted on another type of turbine having other structure

dynamic properties. These test results are not commonly known.

It is known that the occurrence of stall vibrations may be prevented by shutting down operation in high winds. The drawback of this option is that it may result in a reduction in or shut-down of the operation already at wind speeds in the range of 16- 18 m/s., while modern wind turbines otherwise usually are expected to have a cut-out wind speed of 25 m/s.. The loss of production resulting from the shut-down of the operation in the frequently occurring higher wind speeds are in many instances unacceptable.

It is also known that stall vibrations may be dampen by built-in vibration dampers in the blades. The drawback of this option is that the mere size of a vibration damper for a large wind turbine blade is considerable and substantial costs are thus incurred at the use thereof and further in many cases maintenance is required.

Apart from the possibility of built-in vibration dampers no methods for damping stall vibrations are presently known.

It is known that the lift properties for a blade cross-section with a given profile may be altered in various ways. One way is to mount a turbulator on or close to the leading edge of the blade. The use of such turbulators on aeroplanes are known. On wind turbines turbulators in form of stall strips are exclusively used for adjusting the power curve of the turbine or in particular cases for altering the noise emission of the blade.

Brief Description of the Invention

The object of the invention is to provide a particularly simple manner for damping or preventing stall vibrations.

According to the invention the use of a turbulator on the leading edge of a wind turbine blade result in a hitherto unknown and surprisingly advantageous damping or a complete removal of stall vibrations in situations, in which stall vibrations otherwise would be expected due to the combination of wind turbine blade and wind turbine structure used,

and in which stall vibrations hitherto have been considered a serious problem which could only be solved satisfactorily by using built-in vibration dampers.

Similar advantages are obtained in a wind turbine which according to the invention is characterised in that it comprises a number of turbulator segments aligned and evenly interspaced along the leading edge of the blade.

The invention thus enables operation of types of wind turbines, where the cut-out wind speed hitherto has had to be reduced due to the risk of stall vibrations in wind speeds up to the normal cut-out wind speed of typically 25 m/s.. As result the profitability is improved considerably.

Compared to vibration dampers the present invention is advantageous in that a built-in device of a considerable size and maintenance thereof is not required.

Furthermore the invention is advantageous in that it is very suitable for subsequent mounting. Thus, in a wind turbine in which the combination of structure dynamics and aerodynamic allows stall vibrations said vibrations can be dampened or prevented by means of the present invention in a particularly simple and inexpensive manner.

Finally the invention is advantageous in that an embodiment thereof, which is very effective in damping stall vibrations, also has a positive influence on the power curve of the wind turbine. As a results a particularly surprising effect of the invention is obtained.

Advantageous embodiments of the invention are disclosed in the sub-claims.

The expression "stall vibrations" (sometimes denoted stall-induced vibrations) on wind turbines have been used since the 1980'ies. However, the first observations of this phenomenon on large wind turbines have later proved to be misinterpreted. In practice only in recent years has the phenomenon been found in commercial wind turbines. Consequently the knowledge available about the phenomenon, its origin and the remedy

thereof is rather limited.

Based on their own tests the inventors have the following understanding of stall vibrations:

In operation, the blades of stall regulated wind turbines may be in a state in which the aerodynamic damping is small or negative. At very negative damping the total damping, which is the sum of the aerodynamic and the structural damping, can become negative. The wind turbine may then become self-excited. The vibrations do not necessarily depend on a coupling between the individual blades and most likely the vibrations have high amplitudes in flap-wise direction. This type of vibrations was assumed to be observed on the Nibe-A wind turbine in the early 1980'ies, but later measurements revealed that the turbine did not enter into such a state.

Another type of stall vibrations seem to occur when the total damping not necessarily becomes negative, but when the combination of little damping and aeroelastic feedback result in instability. This type of stall vibrations may occur when the edge-wise natural frequency of the blades is close to the second harmonic tilt or yaw frequency. During the vibration per se an aeroelastic coupling takes place between the edge-wise movements of the blades in the first vibration mode and the flap-wise movements in the second tilt or yaw mode. As the deformations at the blade root in flap-wise direction not necessarily are particularly serious in the second mode, the phenomenon is primarily observed by measurements on the blade root as deformation in edge-wise direction. This phenomenon is therefore often called edge vibrations.

Based on the above knowledge, of which much are not commonly known, in general stall vibrations can be dampened or prevented by increasing the aerodynamic damping. Edge vibrations may furthermore be dampened or prevented by altering the dynamics of the wind turbine such that the edge-wise natural frequency is further apart from the second harmonic yaw frequency. The present invention aims at the first solution.

Preferably, the increase in the aerodynamic damping is obtained by using aerodynamic

modifications which do not impair the aerodynamic permanence of the dampened blade. Tests have shown that turbulators arranged on the leading edge of the blade are suitable for this purpose. The detailed understanding of how the increased aerodynamic damping is obtained is not quite established, inter alia as the damping conditions at normal, non-modified, aerodynamic profiles on wind turbine blades are not quite established. It is assumed that the effect is due to a combination of partly a reduced Cl-max. (maximum lift coefficient) of the modified profile and partly (and partly as a result of the reduced Cl-max.) a reduced hysteresis loop of the profile in stall. Moreover - although depending on the practical design - the turbulator comprises the feature that it in its stall state is able to effect a considerably larger area of the blade and not merely the area immediately behind the turbulator. This effect enables a turbulator of a length of only 2-3 % of the length of the blade to effectively dampen the edge vibrations.

Brief Description of the Drawings

Advantageous, practical embodiments of the invention are explained in detail below. Reference is made to the drawings, in which

Fig. 1 illustrates an example of stall vibrations,

Fig. 2 is a diagrammatic view of a known turbulator arranged on the leading edge of a wind turbine blade,

Fig. 3 is an example of how the use of the turbulator in Fig. 2 removes stall vibrations,

Fig. 4 is an example of how the turbulator may be arranged in segments,

Fig. 5 is an example of how the segmented turbulator improves the power curve of the wind turbine.

Best Mode for Carrying out the Invention

Fig. 1 illustrates an example of stall vibrations. The figure illustrates the relation between different parameters and time of a vibration course, the time in seconds being indicated on the abscissa. From the top the ordinate shows:

A: the wind speed (m/s.);
B: power (kW);
C: the flap-wise blade root moment;
D: the edge-wise blade root moment;
E: the tilt moment;
F: the rotation moment; and
G and H: the moment in the tower base in two directions perpendicular to each other.

All moments are presented as uncalibrated output voltage from strain gauge amplifiers. Prior to the occurrence of vibrations the signal for the edge-wise blade root moment is dominated by the dead load. At the approximate time 1 the vibrations begin when the wind speed exceeds the limit of the stable state. The vibration reaches its maximum amplitude at the time 2, said amplitude being considerably above that caused by the normal load from the dead load and reduces the life of the blade considerably, if not controlled.

Fig. 2 illustrate an example of a turbulator in form of a stall strip 3 having an equilateral, triangular cross section with a side length of approximately 10 mm. The turbulator is arranged on the leading edge of the blade 4 in the stagnation point. The strip has a length of 500 mm and is arranged from 3300 mm from the blade tip and towards the centre.

Fig. 3 is an example of how the use of the turbulator in Fig. 2 removes stall vibrations. The figure comprises two x-y diagrams of the edge-wise blade root moment versus the wind speed in m/s.. The moment is rendered as uncalibrated output voltage from strain gauge amplifiers. The mean values are shown in the x-y diagrams by means of a cross and the minimum and maximum values by means of a dot. In one diagram (Fig 3A), which is recorded prior to the use of the turbulator according to the invention, the

blades begins to vibrate at approximately 16 m/s. at which point the minimum and maximum values diverge from the mean value. At a slightly higher wind speed, the amplitude of the vibrations become unacceptable. In the second diagram (Fig. 3B), which is recorded after the use of the turbulator according to the invention, the blades do not vibrate at any time and the operation can continue until the normal cut-out wind speed of 25 m/s is reached.

Fig. 4 is a top and front view of an example of how the turbulator may be arranged as stall strips in segments. A 10 mm triangular strip as shown in Fig. 2 is used. Four segments, each of a length of 500 mm, are arranged on the leading edge of a LM 19.1 blade. The outermost segment is arranged with the largest radius of 3300 mm from the tip of the blade 4. The inner segments are evenly interspaced with 1500 mm. The total length of the blade is approximately 20 m.

Fig. 4 illustrates an example of how the segmented turbulator in addition to preventing stall vibrations also improves the power curve of the wind turbine. The figure comprises two x-y diagrams of the power in kW versus the wind speed in m/s. In the x-y diagrams the mean values are indicated by means of a cross and the minimum and maximum values by means of a dot. In one diagrams (Fig. 5A), which is recorded prior to the use of the turbulator according to the invention, the power limitation is only gradual and no actual maximum value is obtained. The desired power of 550 kW is noticeably exceeded. In the second diagram (Fig. 5B), which is recorded after the use of the segmented turbulator according to the invention, the power limitation is very prompt and a particularly beneficial power curve is obtained.

A turbulator and turbulator segments respectively formed as a stall strip with a triangular cross section have been illustrated and described above. However it should be noted that such a stall strip may have any advantageous cross section. Furthermore it should be noted that any turbulence inducing means inducing the intended turbulence may be used as turbulator and turbulator segments respectively.

Claims

1. The use of a turbulator on the leading edge of a wind turbine blade for damping or completely preventing stall vibrations.

2. The use of a turbulator as claimed in claim 1, wherein the turbulator is a substantially triangular strip arranged in or close to the stagnation point.

3. The use of a turbulator as claimed in claim 1 or 2, wherein turbulator has a length of 1-10% of the length of the blade and is arranged on the leading edge from a point 1-20% of the length of the blade from the blade tip and towards the centre.

4. The use of a turbulator as claimed in claim 1 or 2, wherein the turbulator is divided into 2-10 segments, each having a length of 1-5% of the length of the blade and arranged with interspaces of 1-15% of the length of the blade on the leading edge from a point 1-20% of the length of the blade from the blade tip and towards the centre.

5. The use of a turbulator as claimed in claim 1 or 2, wherein the turbulator is divided into four segments, each having a length of approximately 2.5% of the length of the blade and arranged with interspaces of approximately 7.5% of the length of the blade on the leading edge from a point approximately 15% of the length of the blade from the blade tip and towards the centre.

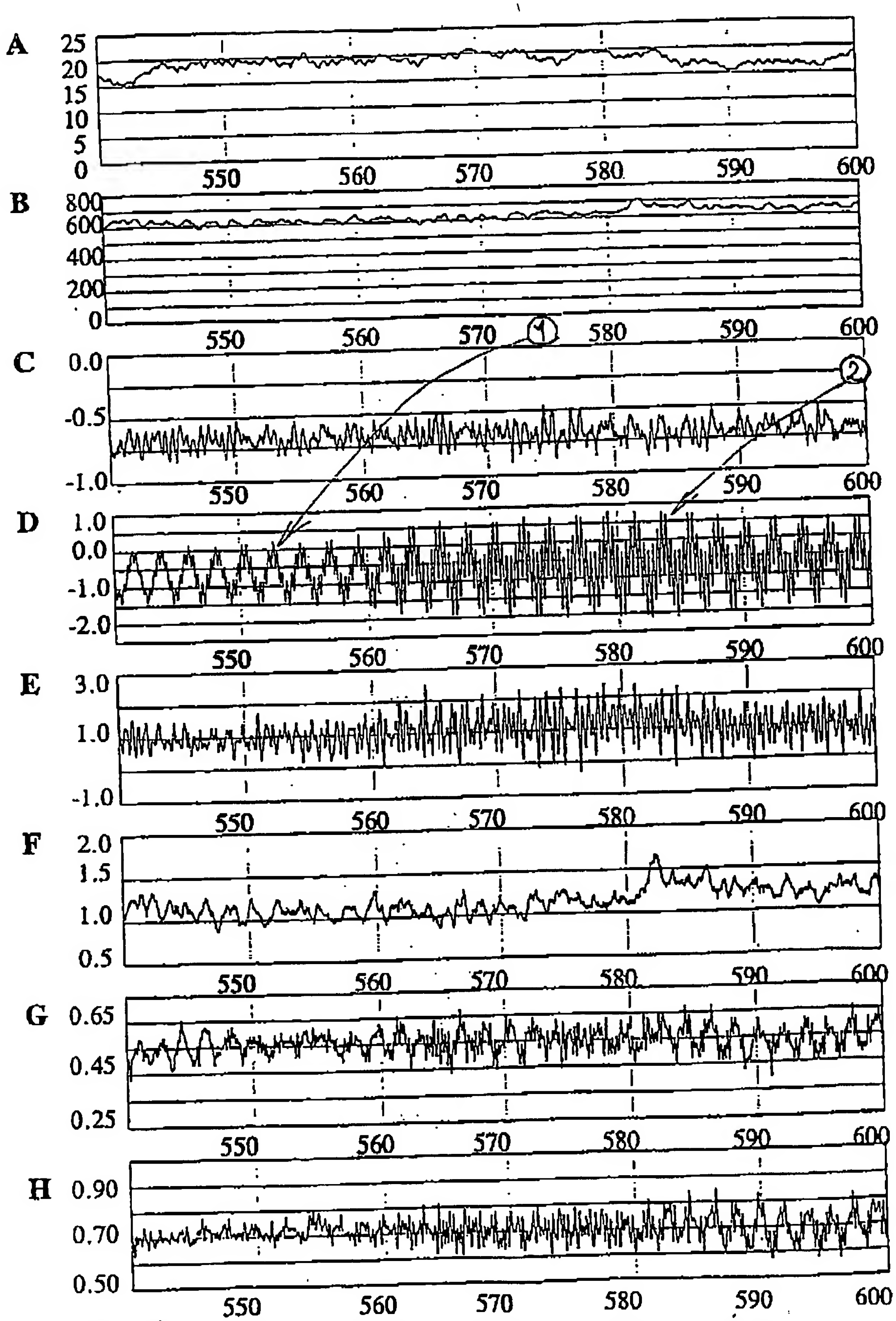
6. A wind turbine having a blade provided with a turbulator, c h a r a c t e r i s e d in that it comprises several turbulator segments aligned and evenly interspaced along the leading edge of the blade.

7. A wind turbine as claimed in claim 6, c h a r a c t e r i s e d in that each turbulator segment is a substantially triangular strip arranged in or close to the stagnation point.

8. A wind turbine as claimed in claim 6 or 7, c h a r a c t e r i s e d in that it

comprises 2-10 turbulator segments, each having a length of 1-5% of the length of the blade and arranged with interspaces of 1-15% of the length of the blade on the leading edge from a point 1-20% of the length of the blade from the blade tip and towards the centre.

9. A wind turbine as claimed in claim 6 or 7, characterised in that it comprises four turbulator segments, each having a length of approximately 2.5% of the length of the blade and arranged with interspaces of approximately 7.5% of the length of the blade on the leading edge from a point approximately 15% of the length of the blade from the blade tip and towards the centre.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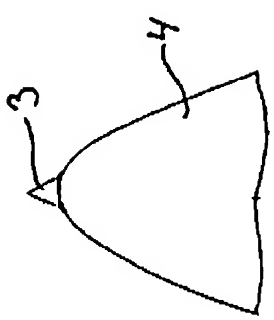

Fig 2

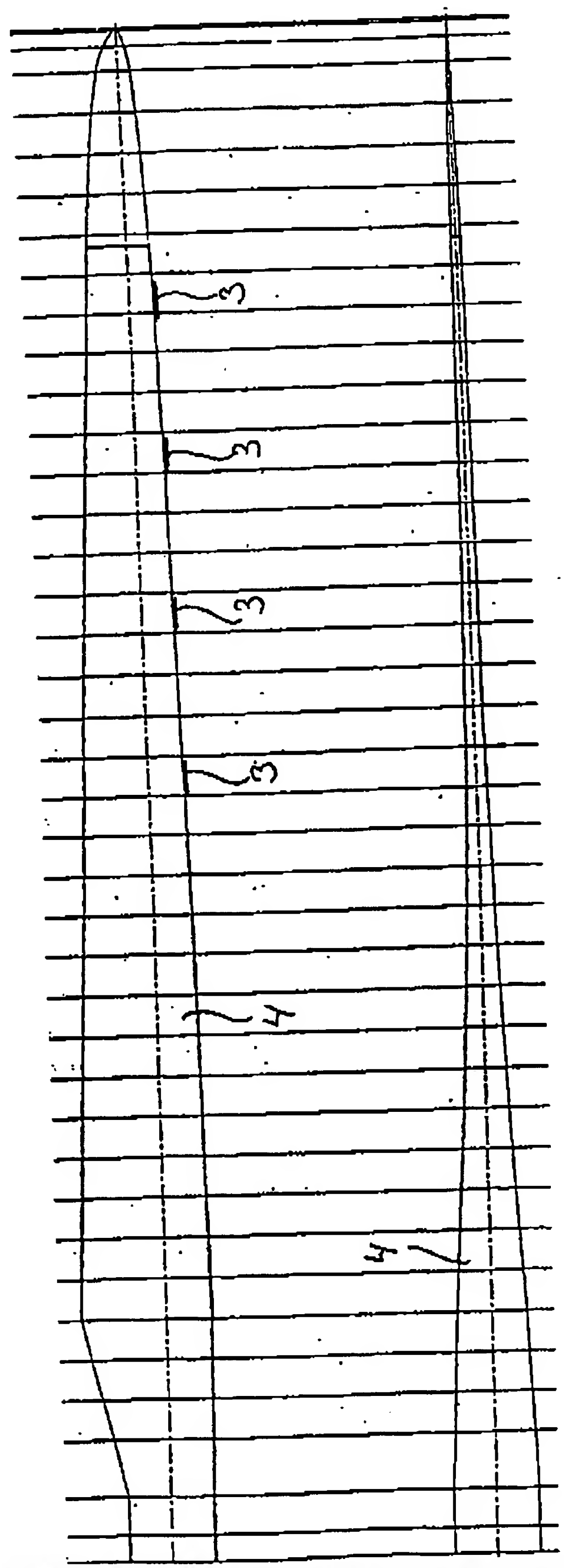

Fig 4

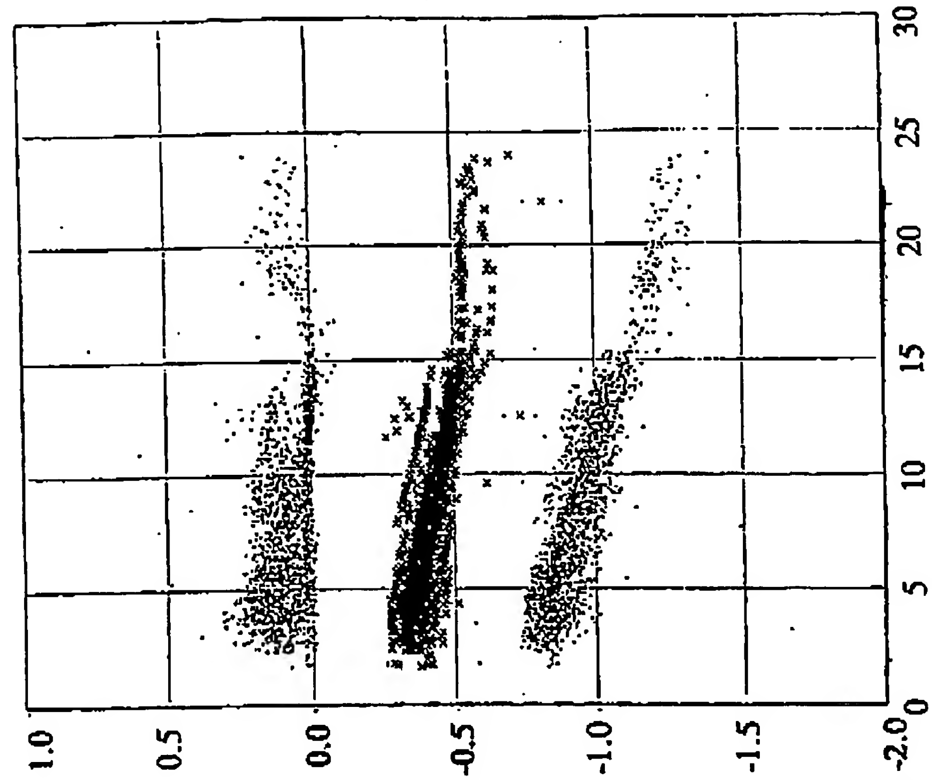

FIG. 3B

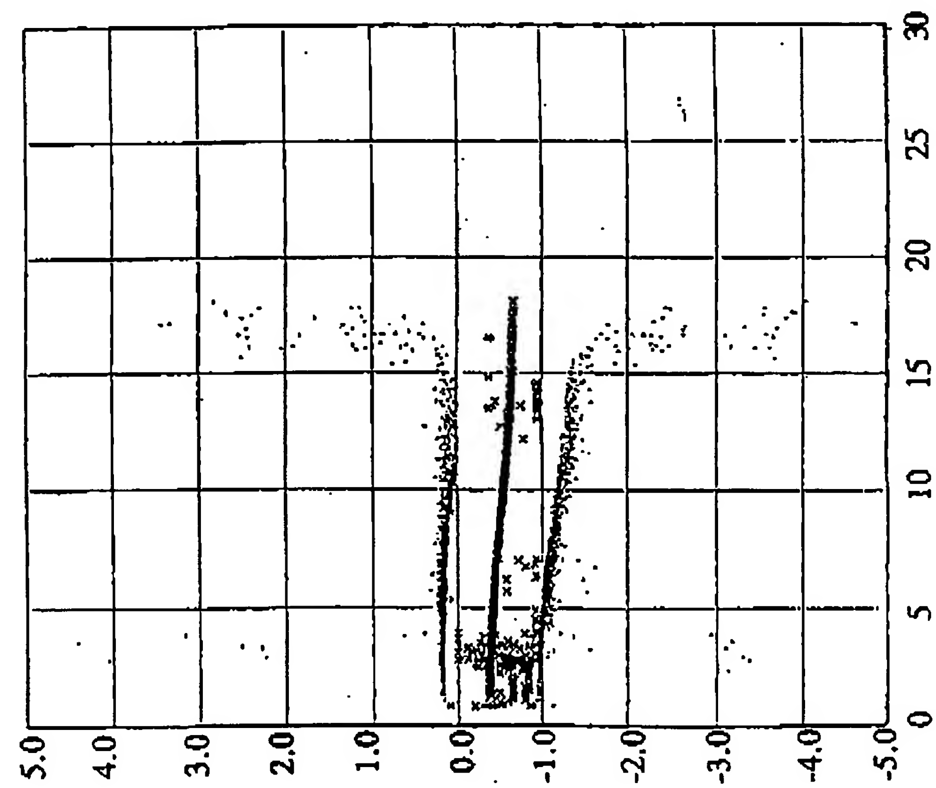

FIG. 3A

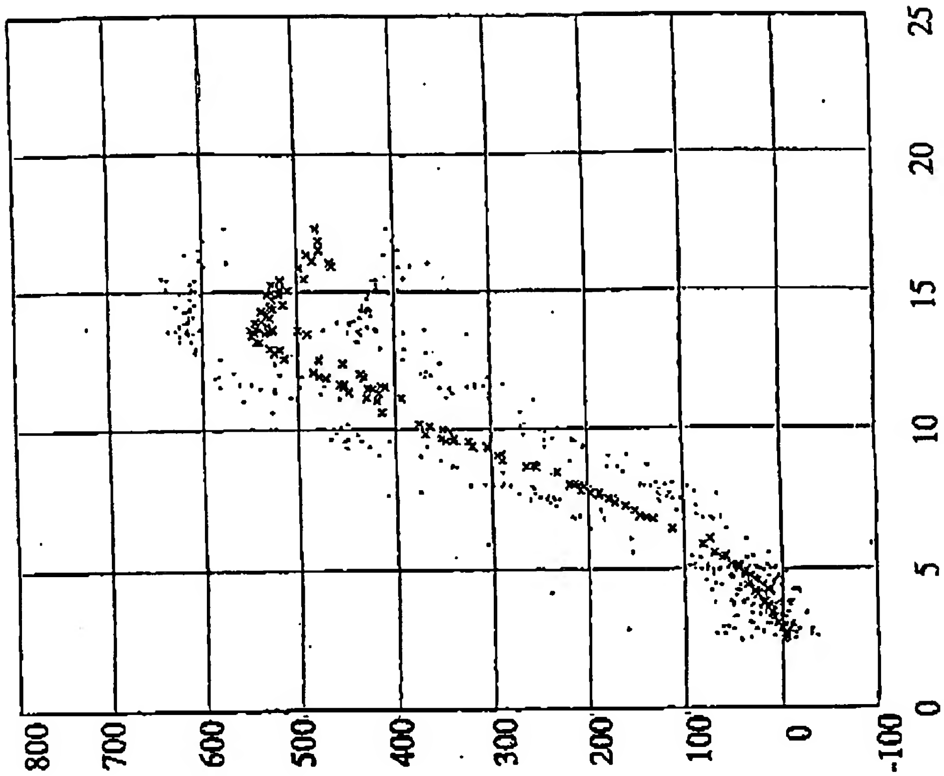
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FIG. 5B

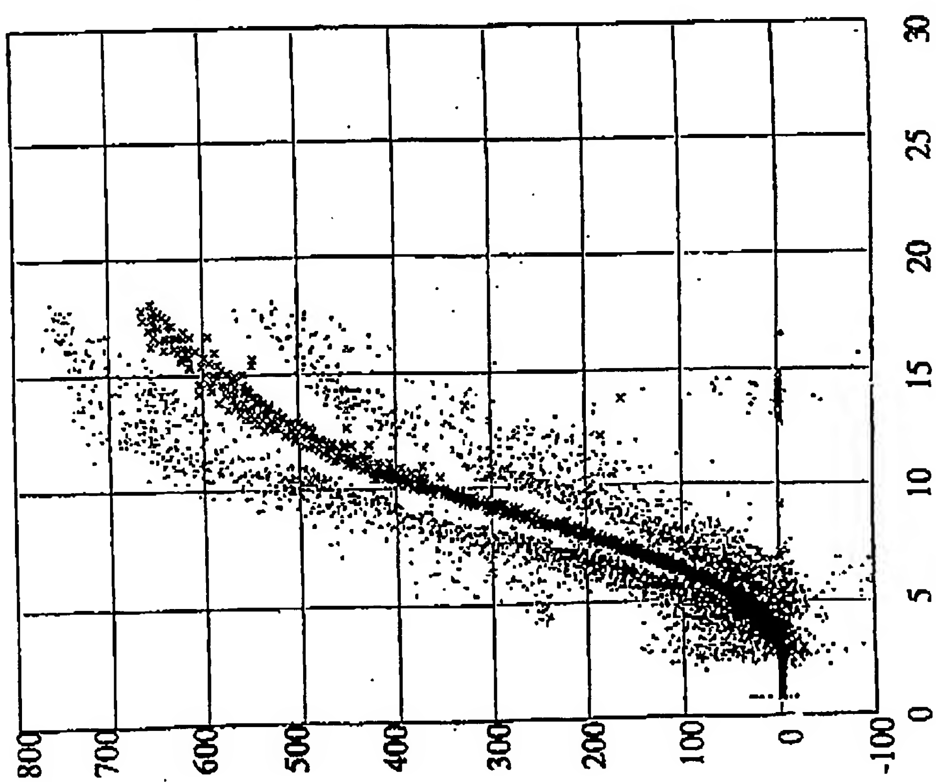
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FIG. 5A

INTERNATIONAL SEARCH REPORT

International application No.
PCT/DK 97/00529

A. CLASSIFICATION OF SUBJECT MATTER

IPC6: F03D 1/06, F03D 7/02, F03D 11/00
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B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC6: F03D, B64C

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

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C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	DK 9500238 W (BONUS ENERGY A/S), 13 December 1996 (13.12.96), figures 1-12, abstract --	1-9
A	Derwent's abstract, No 97-117539/11, week 9711, ABSTRACT OF RU, 2063545 (OBSCHEMASH INZHINIRING CO LTD), 10 July 1996 (10.07.96) -- -------	1-9

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13 February 1998	25 -02- 1998
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INTERNATIONAL SEARCH REPORT

Information on patent family members

03/02/98

International application No.
PCT/DK 97/00529

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
DK 9500238 W	13/12/96	NONE	